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Wind-Diesel Hybrid Systems for Russia's Northern Territories

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ABSTRACT

This paper will summarize the DOE/ Russian Ministry of Fuel and Energy (MF&E) activities in Russia's Northern Territories in the field of hybrid wind-diesel power systems over the last three years (1997–1999). The National Renewable Energy Laboratory (NREL) supplied technical assistance to the project, including resource assessment, system design, site identification, training and system monitoring. As a result, several wind-diesel systems have been installed and are operating in the Arkhangelsk/Murmansk regions and in Chukotka. NREL designed and provided sets of data acquisition equipment to monitor several of the first pilot wind-diesel systems. NREL's computer simulation models are being used for performance data analysis and optimizing of future system configurations.

INTRODUCTION

The Russian Ministry of Fuel and Energy (MF&E) together with U.S. Department of Energy (DOE) and U.S. Agency for International Development (USAID), have joined efforts to bring efficient, competitive, off-grid, renewable energy based power solutions to the Russia's Northern Territories. Currently, most of Russia's Northern inhabitants, approximately 10–15 million people, live without access to the central electricity supply grid. Diesel/gasoline power stations serve as the main source of energy supply on the Arctic coast of Russia. More than 60,000 people are involved in the fuel supply network for Russia's Northern Territories. Thus, substantial funds are spent each year to deliver fuel for the diesel power stations. In addition, the short Arctic summers, insufficient funding, and institutional problems threaten the stability of fuel transportation and supply. The objectives of the DOE/MF&E project are to demonstrate energy and infrastructure cost savings in off-grid wind-diesel applications; to facilitate commercialization of wind technologies; and to establish a technically and economically viable model from which an alternative loan program can be designed by the Russian government.

BACKGROUND

The current Russian-American cooperation in renewable energy was established in September 1993, during the Joint Committee on Economical and Technical Cooperation (JCTC) meeting between Prime Minister Chernomyrdin and Vice President Gore. The agreement was reached to join efforts in examining options for Russia's energy future (thermal/nuclear power, power transmission, energy efficiency, renewable energy and financing). It was followed by a Memorandum of Cooperation signed in October 1993 by Russian Minister of Fuel and Energy Yuri Shafrannik and DOE Secretary of Energy Hazel O'Leary. The Memorandum sets the framework for joint activities in energy efficiency and renewable energy to provide more economical, cleaner energy solutions that yield employment and economic benefits for both countries.

As a result of the above activities, the Joint Coordinating Committee (JCC) in energy efficiency and renewable energy was established during the meeting between Russian deputy minister Bushuev and DOE Assistant Secretary Christine Ervin in October 1994.

NORTHERN RUSSIA'S WIND RESOURCE

The maps shown in Figure 1 identify the areas of renewable energy resource availability for Russia [1]. The centralized grid covers only the European part of the country and Southern Siberia. The rest of the country has access to local grids, or has no grids at all. The wind resource is available in the North and Far East. The highlighted area on the "Wind Energy" map shows the areas with annual average wind speed of 6 m/s and higher. The wind appears to be the only renewable energy resource for the North. The other renewable energy resources (hydro, biomass, and solar) are not available in these regions.

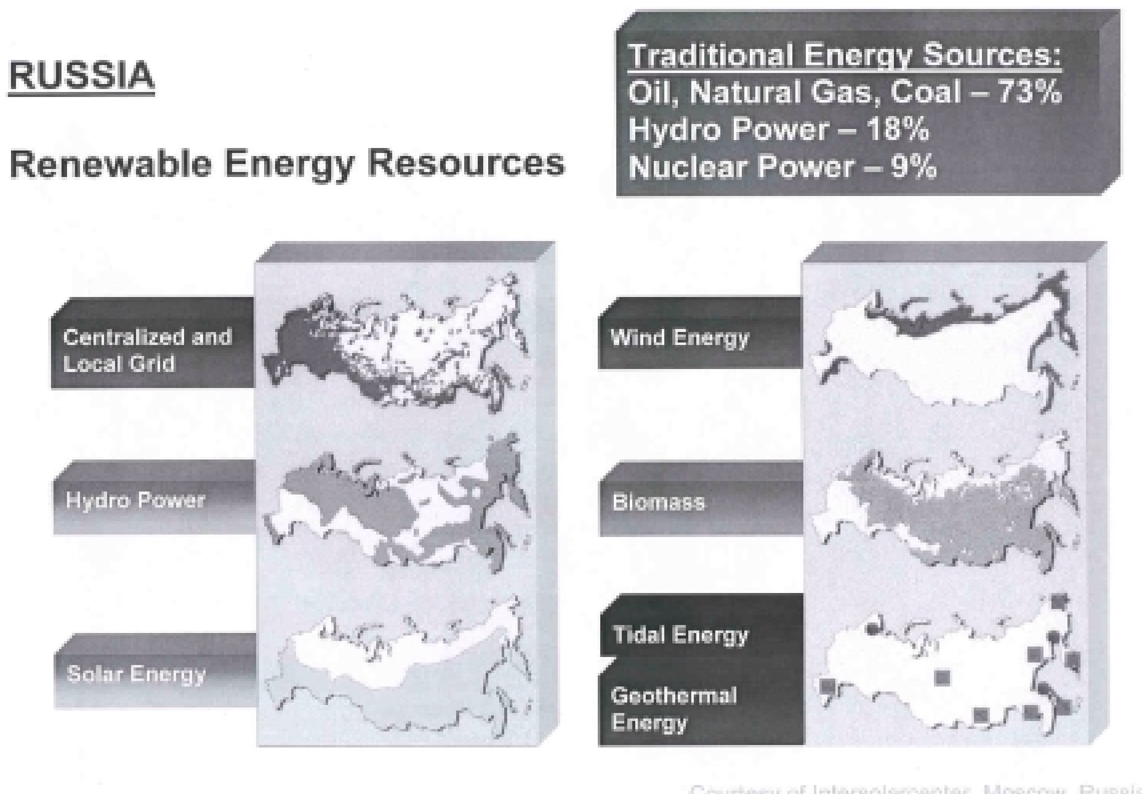

Figure 1: Renewable Energy Resources of Russia

Russia's Northern territories include the European North (Murmansk and Arkhangelsk regions) and the Asian North (Yamal, Taymir, Yakutia and Chukotka regions). These territories, stretched along Russia's Arctic coast for about 7000 km, have enormous wind energy potential. The other areas with large wind potential are located in the Russian Far East (Kamchatka, Magadan, Khabarovsk and Vladivostok regions). The Arctic coast and the Far East of Russia appear to be promising for wind energy development with average annual wind speeds of 6–7 m/s or higher. The fluctuation between the winter maximum and the summer minimum rates is about 30%–40% for the coastal areas. The intensity of the wind resource is less for lower inland where biomass is considered the best alternative energy source.

There are two more prospective wind energy development regions in Southern Russia—the coastal areas of the Azov and Caspian seas. These regions are beyond the scope of work for the current project. However, some studies are being conducted there by the Russian Ministry of Energy and Fuel in order to include them in future activities.

Through the U.S. Department of Energy's (DOE) Initiative for Proliferation Prevention (IPP) program for Newly Independent States (NIS), a program has been established to help facilitate and accelerate the large-scale use of wind energy technologies in areas of Russia that are of interest to the U.S. wind energy industry. A key component of this program is a wind resource assessment project that will reveal the level of wind resource present in specific areas of Russia with the primary focus on the Northern Russian Territories. The major product of this assessment project will be the development of detailed wind resource maps which will use advanced Geographic Information Systems (GIS) technology and sophisticated mapping techniques. New computing techniques will use existing data sets obtained from sources in the United States and Russia. The resultant maps and accompanying summaries of the wind resource characteristics will facilitate the rapid identification of candidate locations for additional wind monitoring and consideration of wind energy development.

U.S./RUSSIAN JOINT COLLABORATION FOR HYBRID WIND-DIESEL SYSTEMS

The first step of the joint collaboration for renewable energy under the JCC framework was establishing two research centers by the Russian MF&E. The first one was the Intersolarcenter (ISC) established at the Russian Rural Electrification Institute (VIESKh) as a sister organization to NREL for joint R&D activities. The second—Federal Center of Small Scale and Unconventional Energy (FC) was established under the Russian MF&E for renewable energy systems certification and deployment, renewable energy policy, and regulation development. Researchers and engineers from both centers work in close contact with NREL.

In 1997, as a part of the agreement, USAID purchased and shipped to Russia 40 wind turbines with batteries and inverters to be installed in Northern Russia. The wind turbines were manufactured by Bergey Windpower Company (BWC) and included thirty 7.5-kW Excel and ten 1.5-kW generators as well as Trojan batteries and solid-state Trace Engineering power inverters. This amounted to a nominal total of 315 kW of wind generating capacity. The list of equipment shipped to Russia is given in Table 1.

The Russian MF&E selected twenty-one sites in the Murmansk, Arkhangelsk and Chukotka regions for the installation of pilot wind-diesel hybrid systems. The candidate project sites were selected on the basis of (1) the infrastructure necessary to maintain the systems, (2) the wind resource, (3) the fuel price and availability at the site, and (4) a variety of applications to serve as pilot projects. System design and training in installation and maintenance were provided by a U.S. team from NREL and BWC. The Russian team was responsible for systems installation, local personnel training, monitoring, and performance analysis of the installed systems. The Federal Center was assigned responsibility for systems installation and operation, and the Intersolarcenter role is mainly in systems monitoring and analytical studies. NREL provided four complete sets of monitoring equipment for the projects.

Table 1: List of Equipment Provided by the U.S. Government

Description	Cost per unit, $	Quantity per unit	Total delivered	Total cost, $
BWC Excel WTG	18,770	1	30	563,100
Tower	8,370	1	30	251,100
Trojan L-16 batteries	5,388	24	720	161,640
Trace SW 4548E inverter	7,395	2	60	221,850
Wind turbine accessories	5,874		30	176,220
Sub total				**1,373910**
BWC 1500 WTG	5,210	1	10	52,100
Tower	3,050	1	10	30,500
Trojan T-105 batteries	775	8	80	62,000
Trace DR 2424E inverter	1,225	1	10	12,250
Wind turbine accessories	3,813		10	38,130
Sub total				**194,980**
Grand Total			**40**	**1,568890**

HYBRID SYTEMS ANALYSIS

The local grids serve only a small portion of remote sites in the Northern Territories. A large number of fishing villages, meteorological stations, lighthouses, and frontier outposts in the Northern territories are supplied with electrical power from small 4–8 kW diesel generators. Diesel fuel prices range from $0.40 to $1.40/liter, and the demand for electricity often exceeds the supply of available fuel. Table 2 shows 12 sites in the Murmansk and Arkhangelsk regions that the Russian Ministry of Fuel and Energy selected for pilot project installation.

Table 2: Potential Hybrid Power System Sites in Northern Russia

No	Site	Long.	Lat.	Diesel Generator, kW	Peak Load, kW	Average wind speed (m/s)	Fuel cost, $ per liter
	Murmansk region						
1	Tzip-Navolok (met. station)	33°10’	69°70’	8	5.5	7.1	0.47
2	Kharlov Island (met. station)	37°40’	68°80’	8	5.5	9.2	0.47
3	Sviatoy Nos (met. station)	39°45’	68°08’	8	5.5	8.3	0.47
4	Vaida Guba (met.station)	33°10’	69°70’	8	5.5	6.9	0.47
5	Svyatonosski Lighthouse	39°45’	68°08’	30	20	8.3	0.4
6	Tuvagubski Lighthouse	33°10’	69°00’	8	5	4.9	0.47
	Arghangelsk region						
7	Morzovetz (met. station)	42°50’	66°70’	8	5.5	7.4	0.47
8	Kanin Nos (met. station)	43°30’	67°80’	8	5.5	8.1	0.47
9	Intzy village	40°70’	65°90’	16	16	5.2	0.40
10	Krasnoe village	53°60’	67°70’	8	8	3.9	0.40
11	Miada village	42°00’	66°30’	100,60,20	112	6.3	0.40
12	Megra village	41°6’	66°10’	60, 20	58	6.3	0.40

The fuel cost for the selected sites is within a range of $0.40–$0.50 per liter, which includes transportation costs. Fuel is much cheaper in the Murmansk and Arkhangelsk regions compared to the rest of Russia’s Northern territories for a number of reasons. All of these sites are geographically closer to the major industrial centers of Murmansk and Arkhangelsk. They are also located in the areas were the Arctic sea never freezes because of warm Atlantic streams that reach the tip of the Cola peninsula.

NREL's task was to select the optimum configuration for each site based on the site information provided by the Russians. The limited amount of equipment was considered as well. The analysis was done using the Hybrid2 simulation code, developed at NREL [2]. After multiple runs of Hybrid2, configuration recommendations were developed, similar to ones shown in Table 3. The optimum number of wind turbines and other equipment for each site that gives the maximum economy of diesel fuel was recommended. Table 2 shows the simulation results for 12 sites in the Arkhangelsk and Murmansk regions. The estimated percentage of fuel saved varies from site to site, depending on the local wind resource, and the type of equipment supplied.

Table 3: Recommended Configurations

No	Site	Number of BWC 1500 wind turbines	Number of BWC Excel wind turbines	Number of T-105 batteries	Number of L-16 batteries	Number of SW inverters	Number of DR inverters	Estimated Fuel saving, %
	Murmansk Region							
1	Tzip-Navolok		1		16	1		84.2
2	Kharlov Island	3		24			3	78.2
3	Sviatoy Nos	3		24			3	72.6
4	Vaida Guba		1		24	1		81.0
5	Sviatonoski lighthouse		3		72	6		84.0
6	Tuvagubski Lighthouse		1		32	1		67.9
	Arkhangelsk region							
7	Mortzovetz		1		24	1		85.0
8	Kanin Nos	3		24			3	74.0
9	Intzy		3		74	3		79.5
10	Krasnoe		4		96	3		70.5
11	Maida		4		96	6		26.0
12	Megra		4		96	3		51.0

PERFORMANCE MONITORING

Another major contribution that NREL is making in this project is to help the Russians monitor the hybrid systems. NREL has provided four data acquisition systems (DAS) that allow monitoring of all basic performance parameters of the hybrid system. The DAS are based on the equipment manufactured by Campbell Scientific and Ohio Semitronics, both U.S. companies. The monitoring equipment includes dataloggers, wind speed and direction sensors, ambient and battery temperature sensors, and various AC and DC current/voltage/power sensors. The purposes for using monitoring systems are

- Determine component and system efficiencies
- Verify proper system functioning
- Provide system trouble shooting
- Detect and analyze significant village load changes
- Calculate actual cost of utilized energy
- Validate models
- Provide information to improve systems to be installed in later stages of project implementation.

The Russian-developed monitoring system will be tested at the demonstration wind hybrid site in Istra, near Moscow. This site is being established with NREL assistance as a training and demo center for Russian technician and engineers who will be involved in implementation of hybrid technologies in Russia.

PILOT PROJECTS

According to the Federal Center, a total of twelve wind turbines have already been installed in the Murmansk and Arkhangelsk regions and Chukotka as of July 1999. Two of these turbines are used in a hybrid system installed in the village of Krasnoe located in the Arkhanglesk region. The map of the region is shown in Figure 2 [3]. This site has been visited several times by NREL staff. The system was installed in 1997 by BWC team. It is the only system so far that has been equipped with a DAS.

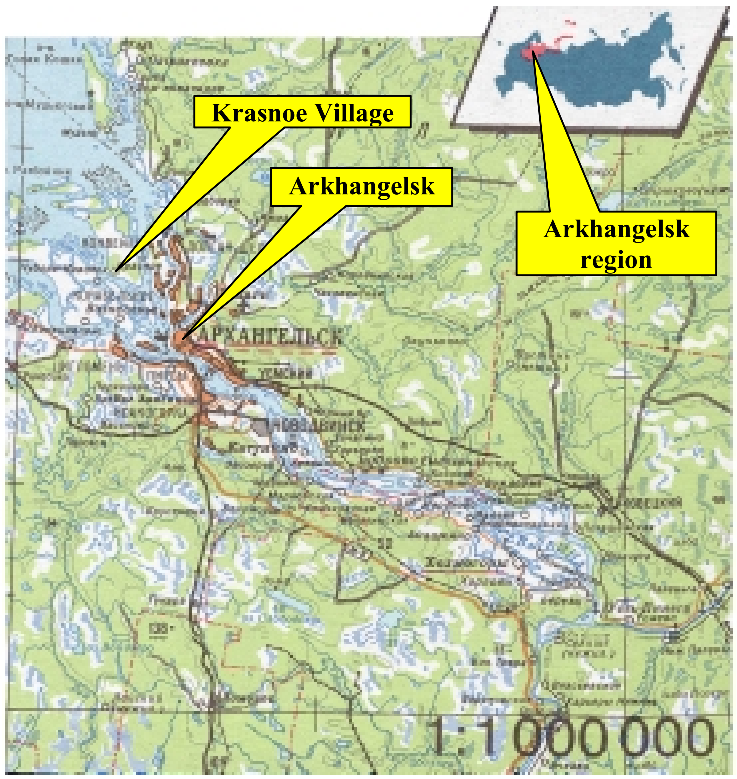

Figure 2: Map of Arkhangelsk region, Russia

The village of Krasnoe is typical of communities in the Northern Territories. It consists of about 30 households and an 8-kW Russian-made diesel generator was the only power source for the village. Krasnoe is an agricultural and fishing community with a very low average household income. The diesel generator was used to provide electrical power to the village for about four hours a day (6:00–10:00 P.M.). The rest of the time the village did not have electric power. In recent years, due to the deepening economic crisis in Russia, villagers could afford even less diesel fuel. Thus, the power supply for the village became extremely irregular. The hybrid system installed in Krasnoe is supposed to provide power to the village on a regular basis.

The diagram of the hybrid system installed in Krasnoe is shown in Figure 3. The system consists of two 7.5-kW Bergey Excel wind turbines on an 18-m tower, connected to a 48 VDC, 200 Ah total capacity battery bank made up of Trojan L-16 batteries. Three 4.5-kW single-phase Trace Engineering SW4845 inverters (220 V, 50 Hz) are connected in parallel to the battery bank on the DC side. On the AC side, the inverters are combined in a way so that they provide three-phase power to the village loads. The system was set up as a switched configuration. Thus no parallel operation of inverters and diesel generator is possible. This was done because the diesel generator is too old and has a poor voltage/frequency control system. The inverters often refuse to recognize the diesel generator as a reliable voltage source and will stop operation. In addition, the diesel generator does not have an automatic start-up option, which is typical for other sites in Northern Russia. This does not allow full use of the inverters' capability to turn the diesel generator on and off automatically depending on battery voltage. As a result, system performance will suffer because of the human factor: it depends on operator judgment when to turn the diesel on or off. This will decrease the overall operational efficiency of the system.

The hybrid system in Krasnoe is shown in Figure 4. The site is located on Nikolski Island, about 15 miles north of Arkhangelsk. The prevailing wind direction is from Northwest and has an average annual wind speed of about 4 m/s. The Russians plan to install one more 7.5-kW wind turbine at the site to increase system's energy production. A photo of the control room with the Trace Engineering inverters and other BWC equipment is shown in Figure 5.

Figure 4: Wind-diesel hybrid system in Krasnoe village

Figure 5: Control room

The hybrid system in Krasnoe is equipped with one of the DAS provided by NREL. The DAS components are shown in Figure 6 and include

- Wind speed, direction and ambient temperature
- DC output currents for each individual wind turbine
- Battery bank voltage, current and temperature
- DC input currents for each individual inverter
- Phase AC power and power factor for each phase.

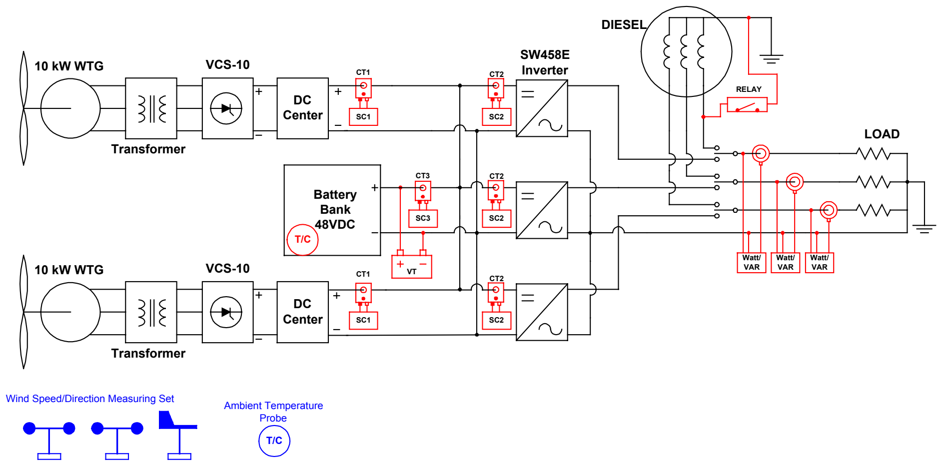

Figure 6: Diagram of the hybrid system in Krasnoe

List of DAS components is shown in Table 4. Three similar sets were shipped to Russia to be installed on other sites. Total cost of the equipment in Table 4 is about $9,000.

Table 4: List of DAS components (by manufacturer)

No.	Description	Qty
	Campbell Scientific, Inc	
1	Datalogger CR10X-2M-XT with accessories	1
2	AM416 – 16 -XT channel. Multiplexer	1
3	PS12LA 12 V regulated power supply	1
4	108-L Temperature Probe	2
5	2:1 voltage divider modules	8
	Ohio Semitronics, Inc.	
6	12973 Current transformer (100:5)	3
7	PC20-002E-22 Watt/VAR/PF transducer (4-20 mA output)	3
8	CTL-200T Current transducers	5
9	CTL-400T Current transducer	1
10	CTA101X5-48 Signal conditioner (0-5 V output)	6
11	VT7-004X5-48 Voltage transducer (0-5 V output)	1
	NRG systems	
12	NRG #40 Maximum Anemometer	2
13	NRG #200P Wind Direction Vane, 10K	1

The other systems were installed in the village Bolshie Kozli (Arkangelsk region), Sosonovka (Murmansk region), Mirni (Cheliabinsk region), and in Chukotka. NREL is studying and evaluating the information of these systems provided by the Russians that is to be presented in future publications.

Figure 7 shows the wind speed and load data measured at the site in June of 1999 by NREL staff during their last visit to Russia. The measurements were taken over about 4.5 hours of operation. The wind speed was measured on both wind turbines and the AC power to the load was measured in all three phases. The first thing that can be noticed from the power profile is the extreme imbalance between phases. This kind of load profile is typical for small villages in Northern Territories.

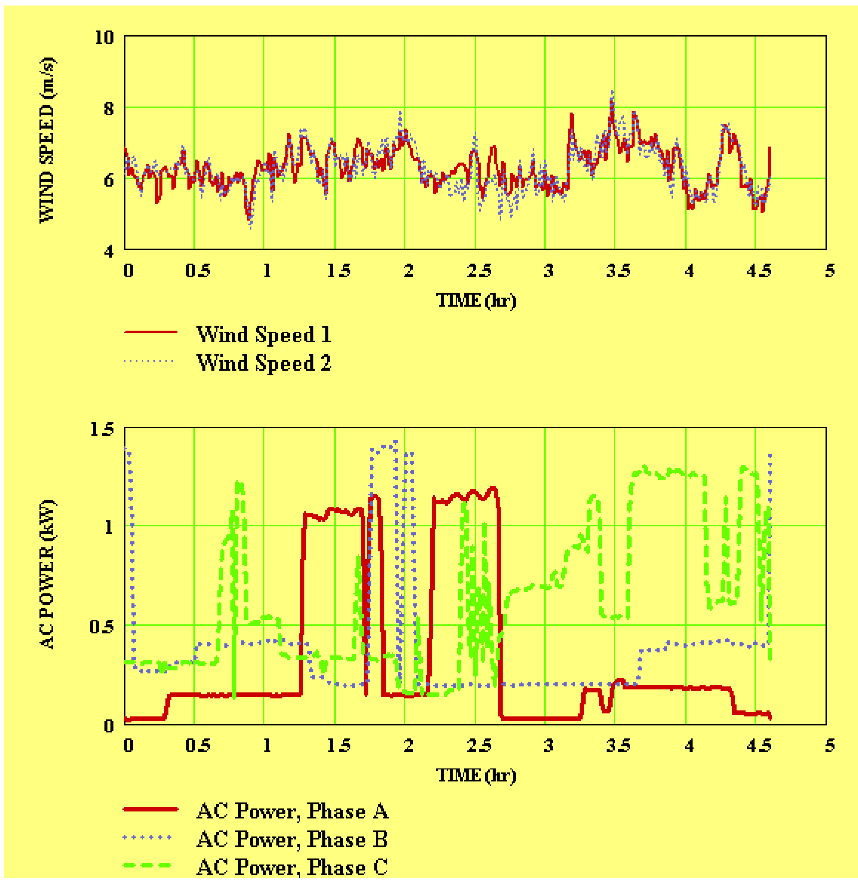

Figure 7: Wind speed and load data

CONCLUSIONS AND LESSONS LEARNED

The following main conclusions can be drawn after installation of 12 wind turbines and based on accumulated project experience:

- Russian diesels are old and often have not been properly maintained. They usually don't have an operational automatic start- up circuitry. So, automatic operation with inverters is not possible.
- No problems have been recorded so far with the Bergey wind turbines**.** All 12 of them have survived through two consecutive winters with no breakdown or malfunction.
- Qualified technicians and engineers are available almost everywhere in Russia, resulting in proper operational conditions and maintenance of installed hybrid systems.
- Direct contact with local authorities helps to speed up the project implementation schedules significantly.

- Better fuel usage records are necessary to conduct economic analysis. Valid records or data on fuel consumption do not exist for most of the sites. The option of using some fuel metering equipment as part of the DAS is being considered.

FUTURE PLANS

The following activities were included in the next five-year hybrid systems cooperation plan between DOE and the Russian Ministry of Fuel and Energy:

- Complete installation of the remaining systems in Northern territories
- Complete testing of the Russian-made monitoring equipment prior to installation at the remaining sites
- NREL will continue providing technical assistance
- The Russian Ministry of Fuel and Energy will attempt to secure a $300 million loan to retrofit 900 sites in Northern Russia using similar systems as the pilot sites above. These new sites may also require the installation of controls on existing diesel generators.
- Complete development of wind resource atlas for Northern Russia which is currently being developed by the Intersolarcenter under an NREL subcontract.

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